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ABSTRACT

Mathematics and science standards were created in response to concern throughout the United States about the performance of students in these areas and the demands of an increasingly scientific and technological world. Educators and community leaders recognize that students will need more mathematical and scientific knowledge both in their jobs and in their every day lives. The standards reflect current thinking about how students learn, emphasizing practices that allow students to construct their own knowledge and take an active role in the learning process. The national standards for mathematics and science provide clear goals for students and teachers, outlining what students should know and be able to do. The teaching strategies called for in the standards are closely tied to those of authentic pedagogy which include instructional activities that involve active learning. This publication summarizes the vision and rationale presented in the national standards documents and current literature on the topic. Strategies and resources for implementing a standards-based teaching approach are the main focus of this report. Sections include: "The Purpose of Standards"; "National Mathematics Standards"; "National Science Standards"; "Mathematics Teaching Standards"; "Science Teaching Standards"; "Implementing the Standards" and "Professional Development". Ten resources, 8 support organizations, and 17 on-line resources are listed. Contains 41 references. (DKM)

Science and Mathematics Standards in the Classroom

It's Just Good Teaching

Northwest Regional Educational Laboratory

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Science and Mathematics Standards in the Classroom

It's Just Good Teaching

by Jennifer Stepanek
Science and Mathematics Education

June 1997

Northwest Regional Educational Laboratory

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Preface

The publication of the NCTM *Curriculum and Evaluation Standards for School Mathematics* in 1989 initiated a new era in the quest for quality mathematics and science education for all students. It was followed by the development and release of the NCTM *Professional Standards for Teaching Mathematics* and the *Assessment Standards for School Mathematics*, the American Association for the Advancement of Science's *Science for All Americans* and *Benchmarks for Science Literacy*, and the *National Science Education Standards* by the National Resource Council. These documents further articulated what students should know and be able to do in science and mathematics. Along with state and local standards, they provide the education community with tools that guide and support ongoing efforts to develop and deliver effective teaching and learning in schools across the region. Recognizing that teachers are key to students achieving higher academic standards, the current challenge in standards-based reform is shifting from articulating the vision and defining the standards, to implementing the necessary instructional strategies and practices in the classroom.

This document, *Science and Mathematics Standards in the Classroom*, summarizes the vision and rationale presented in the national standards documents and current literature on the topic. However, in response to the frequently heard questions, "What does it look like in the classroom?" and "How do I do it?", strategies and resources for implementing a standards-based teaching approach are the main focus of this report. This most recent addition to the "It's Just Good Teaching" series serves as a companion to two previous products, *Science and Mathematics for All* and *Inquiry Strategies For Science and Mathematics Learning*. The next publication in the series will focus on the use of classroom assessment strategies to inform and guide instruction.

The Science and Mathematics Education unit at the Northwest Regional Educational Laboratory offers this series as one aspect of our continuing efforts to support and assist Northwest educators as they strive to provide all students with the mathematics and science knowledge, skills, and abilities necessary for success. Your feedback and guidance facilitate our commitment to collaborate and respond to the needs of the region. We look forward to hearing from you.

Kit Peixotto
Unit Manager
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June 1997

Introduction

In 1989, the National Council of Teachers of Mathematics (NCTM) published the *Curriculum and Evaluation Standards for School Mathematics*, followed closely by the *Professional Standards for Teaching Mathematics* in 1991 and the *Assessment Standards for School Mathematics* in 1995. Recently, the *National Science Education Standards*—which also addresses content, teaching, and assessment—was published after several years of development. Many districts and states in the Northwest have adopted these national standards into their educational goals and benchmarks.

The mathematics and science standards were created in response to nationwide concern about the performance of students and the demands of an increasingly scientific and technological world. Educators and community leaders recognized that students will need more mathematical and scientific knowledge, both in their jobs and in their responsibilities as society members. The standards reflect current thinking about how students learn, emphasizing practices that allow students to construct their own knowledge and take an active role in the learning process. In addition, the standards are grounded on the principle that all students can rise to meet high expectations (National Council of Teachers of Mathematics [NCTM], 1989; National Research Council [NRC], 1996).

In short, the national standards for mathematics and science provide clear goals for students and teachers, outlining what students should know and be able to do. They were developed from the experiences of educators, research on effective practices, and expertise in mathematics and science content areas. The standards call for a level of mathematical and scientific understanding that goes beyond mere knowledge of facts and procedures. While factual knowledge and rote skills are important, the standards reflect the widespread belief that students must also use problem-solving, reasoning, and communication skills in order to fully develop understanding and the ability to apply their knowledge.

There is initial evidence that standards-based teaching can have a positive impact on student achievement. The teaching strategies called for in the standards are closely tied to those of authentic pedagogy: instructional activities that involve active learning. This means that students solve complex problems and construct meaning that is grounded in real-world experiences. Newmann, Marks, and Gamoran (1996) recently completed a national study of student achievement in schools undergoing restructuring. They found strong evidence that authentic pedagogy has a positive impact on student performance at all levels, regardless of race or gender. They also found that active learning alone does not guarantee higher student achievement, but

that these strategies must be rooted in high intellectual standards (Newmann, Marks, & Gamoran, 1996).

If the standards are to have any value or make any impact, educators must put them into practice. Although the standards are not new, they have not been fully implemented and there are many indications that teachers need more information about them. The standards describe a way of teaching and a level of achievement that is radically different for many teachers and students. Teachers are being asked to implement instructional practices that most of them have never experienced themselves. In addition, the standards provide only an outline, not explicit directions for implementation (Wasley, Donmoyer, & Maxwell, 1995).

Implementing the standards is not an easy process, and it will not occur quickly. Teachers are being asked to change the way that they teach and to unlearn some of their professional training, as well as the model of teaching they received throughout their education. Parents and administrators are often suspicious of unfamiliar expectations and teaching methods. Students can be resistant to innovative classroom practices. Making changes requires a lot of time—for reflection, for planning, for collegial activities—more time than teachers may be able to find in overcrowded school schedules. Most of all, there is no one recipe for standards-based teaching (Leinwand, 1992; Wiske & Levinson, 1993).

The purpose of standards

Some educators have been reluctant to employ the standards because they interpret them as a rigid set of rules that go against student-centered principles of learning (Jervis & McDonald, 1996). However, the stated purpose of the standards is to ensure quality and to indicate goals (NCTM, 1989), not to make teaching and learning standardized and uniform. The mathematics and science standards are not intended to be mandates for where every student should be at each grade level. They are not meant to be used only as benchmarks for assessment. The standards are based on constructivist theories of learning, and recognize that students learn in different ways and at different rates (NCTM, 1991; NRC, 1996).

Standards can provide many advantages for both teachers and students. They formalize high expectations for all students. They set criteria for more challenging classrooms, enriching curriculum content and expanding access to improved

learning. Standards also offer a framework for authentic pedagogy: curriculum focused on active learning of important concepts and complex themes (Wheelock, 1995).

Standards are an important and effective tool because they express clear expectations for students and teachers, which research indicates is a key component in promoting student success (Cotton, 1995). Students benefit because they have specific information about what they need to do in order to succeed. Teachers benefit because they have clear goals and learning becomes more purposeful (Harris & Carr, 1996).

National mathematics standards

The classrooms envisioned in the NCTM *Curriculum and Evaluation Standards* are places "where interesting problems are regularly explored using important mathematical ideas." The NCTM standards focus on meaningful problems and active learning. They are based on the premise that *what* students learn is dependent on *how* they learn it. The standards outline five general goals for all students:

- **Learn to value mathematics.** Students should appreciate the role of mathematics in the development of our contemporary society and explore relationships among mathematics and the disciplines it serves.

- **Become confident in one's own ability.** Students need to view themselves as capable of using their growing mathematical power to make sense of new problem situations in the world around them.

- **Become a mathematical problem solver.** Students need to work on a variety of problems that may take hours, days, and even weeks to solve, that require both independent and cooperative work, and that are both formulated and open-ended.

- **Learn to communicate mathematically.** Students should be given problem situations in which they have an opportunity to read, write, and discuss ideas so that the language of mathematics becomes natural to them.

- **Learn to reason mathematically.** Students should learn to make conjectures, gather evidence, and build arguments to support their solutions and ideas.

Mathematics has traditionally been taught as a way to solve individual problems. The standards promote a shift to teaching mathematics as a way of thinking that includes speculation, identifying patterns and examining characteristics, and using examples to test hypotheses about mathematical relationships. The standards emphasize that mathematics should be meaningful and contextual, and that students should learn about the applications of mathematics to real-world problems. Learning mathematics should engage students and include opportunities to formulate problems and questions based on their own interests: Teachers encourage students to become independent thinkers and self-directed learners (NCTM, 1989).

National science standards

The *National Science Education Standards* (NSES) was developed on the premise that science is an active process: "Students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills" (NRC, 1996).

The standards are based on four overall goals for school science:

- Students should be able to experience the richness and excitement of knowing about and understanding the natural world.

- Students should be able to use appropriate scientific processes and principles in making personal decisions.

- Students should be able to engage intelligently in public discourse and debate about matters of scientific and technological concern.

- Students should be able to increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers.

The science standards emphasize connecting science disciplines such as biology, chemistry, and physics, as well as connecting those disciplines to other subjects. The standards identify unifying concepts that are common to all the sciences and that help students make

connections. These concepts include systems, change, measurement, form and function, and evolution. Like the mathematics standards, the science standards require students to understand scientific concepts and develop the abilities of inquiry rather than merely memorizing facts and information. Students focus on using evidence and strategies for developing or revising an explanation. Students conclude activities by not only stating the results of an experiment, but also by applying those results to scientific arguments and explanations (NRC, 1996).

Both the mathematics and science standards "aspire to be guides to teaching and learning experiences...that engage students in experiencing and understanding the disciplines' bodies of knowledge as a set of dynamic ideas rather than as a collection of facts" (Wheelock, 1995). The standards share an emphasis on learning and teaching for understanding, which Harvard University's Teaching for Understanding Project defines as "a matter of being able to do a variety of thought-demanding things with a topic—like explaining, finding evidence and examples, generalizing, applying, analogizing, and representing the topic in a new way" (Perkins & Blythe, 1994). The shift toward reasoning and problem solving envisioned by the standards requires teaching strategies and learning environments that can be very different from current practices.

Professional teaching standards for mathematics and science

Both the national mathematics and science standards emphasize that teachers play the key role in implementation. For this reason, teaching standards were developed to help guide and assist teachers in modifying their instructional practices. The mathematics and science professional standards describe instructional practices that foster the level of understanding called for in the content standards. They suggest roles that teachers might engage in to make such learning possible, and they provide guidelines for teachers to consider when designing or selecting tasks (Ball, 1992).

The teaching standards are a useful tool for implementing the content standards, but they are not meant to dictate instructional practices. Standards cannot directly determine teachers' actions and decisions. At best, the role of standards is to "profess a prevailing view, orienting individuals and institutions toward collectively valued goals without necessarily mandating specific sets of procedures" (Ball, 1996). For this reason, the standards do not require teachers to follow specific steps. Although

both the mathematics and science standards documents include classroom vignettes and examples, they do not outline the specifics of day-to-day practice. Instead, the standards address the four major aspects of teachers' work in the classroom: planning tasks, guiding discourse, creating a positive learning environment, and evaluating teaching and learning.

Mathematics teaching standards

The *Professional Standards for Teaching Mathematics* describes the central aspects of good mathematics teaching across all grade levels:

■ Teachers **pose tasks** that are based on significant mathematics; knowledge of students' understanding, interests, and experiences; and the diverse range of ways that students learn mathematics. Tasks should develop students' mathematical understanding and skills, promote communication, and call for problem solving, problem formulation, and reasoning.

■ Teachers **orchestrate discourse** by posing questions and tasks that engage and challenge students, by listening to students' ideas, and by monitoring participation. Teachers ask students to clarify and justify their thinking, both orally and in writing. They also decide when and how to provide information and when to let a student struggle with a difficulty.

■ Teachers **promote discourse** in which students listen to, question, and respond to one another; initiate problems and questions; and use a variety of tools to reason, make connections, solve problems, and communicate.

■ Teachers **encourage and accept the use of technology,** including calculators and computers; pictures, diagrams, and graphs; and oral presentations and dramatizations in order to enhance discourse.

■ Teachers **create a learning environment** that provides the time necessary to work with significant ideas and problems. Teachers respect and value students' ideas and encourage them to take risks by raising questions and formulating conjectures.

■ Teachers **engage in ongoing analysis of teaching and learning** in order to make plans, adapt activities, and challenge and extend students' ideas. Teachers observe and listen to students and examine the effects of the tasks, discourse, and environment on students' knowledge, skills, and dispositions.

Science teaching standards

The teaching standards in the *National Science Education Standards* identify "inquiry into authentic questions generated from student experiences" as the primary strategy for teaching science. They cover much of the same ground as the mathematics teaching standards:

- Teachers **plan an inquiry-based science program,** selecting and adapting content to the interests and abilities of the students, and using teaching and assessment strategies that promote student understanding.

- Teachers **guide and facilitate learning,** orchestrating discourse, focusing and supporting student inquiries, and challenging students to share responsibility for their own learning. Teachers also respond to student diversity and encourage all students to participate.

- Teachers **engage in ongoing assessment** of their practice and of students' learning, using multiple methods and guiding students in self-assessment. Teachers use data on student progress, observations of teaching, and interactions with colleagues to reflect on and improve instruction and to report student achievement.

- Teachers **design and manage learning environments** that provide students with the time, space, and resources they need. This includes creating a setting that is flexible and supports inquiry, as well as engaging students to assist with the design of the learning environment.

BEING A STANDARDS-BASED TEACHER MEANS BEING AWARE OF THE TARGETS AND HAVING A PLAN FOR HOW TO REACH THEM. THE TARGETS ARE TAILORED TO THE STUDENTS IN THE CLASS: THE STANDARDS GUIDE INSTRUCTION, BASED ON WHERE THE STUDENTS ARE AND HOW BEST TO GET THEM WHERE THEY NEED TO GO.

—*TIFFANY SANTOS, MATHEMATICS FACILITATOR*

- Teachers **develop communities of learners** that reflect the intellectual rigor and social values of scientific inquiry. Teachers display respect for students' diverse ideas, skills, and experiences and nurture collaborations among students. They also enable students to have a voice in decisions about the content and context of their learning.

- Teachers **help plan and develop the school science program,** including allocation of time and other resources and implementation of professional development strategies.

Implementing the standards

Ultimately, it is the class and the needs of the students that determine instructional practice. Teachers will need to tailor their approach to the standards based on

knowledge of their students. The standards apply to all students, in spite of their different needs, backgrounds, and learning styles. The standards require schools to focus on helping all students meet high expectations.

There is a danger of interpreting the standards as strict mandates in which all students are expected to work toward the same goal at the same time and in the same way. This approach is contrary to the purpose of the standards, which require that each student be seen as an individual. The focus is not exclusively on the goals and products but also on the process of learning, and developing a deep understanding of mathematics and science.

The following strategies are recommended to increase students' depth of understanding and problem-solving abilities (Ornstein, 1995):

☐ Present students with questions or problems to solve rather than answers to copy

☐ Incorporate and challenge students' prior knowledge

☐ Have students make predictions and then test their ideas

☐ Allow students to experiment and explore rather than limiting them to one way of working or finding an answer

☐ Incorporate students' planning and ideas into the curriculum

☐ Facilitate a variety of hands-on experiences

☐ Assign independent projects and reading, allowing students to pursue their own interests and questions

"No set of principles can guarantee a recipe for good practice. Teaching entails weaving together many different kinds of knowledge and insight. It involves weighing and considering competing notions and commitments, making tough choices, and analyzing and reflecting carefully on the consequences of actions and decisions" (Ball & Schroeder, 1992).

New classroom roles. The standards encompass a change in the teacher's role and in the students' responsibilities. "Teaching to develop problem-

Standards-based teachers:

Focus on the process of science and mathematics, rather than on right answers

Encourage students to describe their thinking verbally and in writing

Enable students to view science and mathematics as valuable and interesting areas of learning

Encourage students to become more self-reliant and validate their own answers

Help students to be persistent with problems not solved on the first attempt and to try alternative solutions

Demonstrate and model scientific and mathematical ideas in a variety of ways

Enable students to become problem solvers and users of science and mathematics in their everyday lives

(Rowan & Bourne, 1993)

solving, reasoning, and communication skills requires a very different style of instruction from teaching technical skills.... Reform is about teaching for understanding and teaching to promote students' confidence in themselves as learners and doers [of mathematics and science], rather than teaching students to be proficient at executing standard procedures" (Lappan & Briars, 1995).

In standards-based classrooms, teachers are no longer the source of knowledge, but facilitators of students' learning. Instead of dispensing information and giving students answers, teachers focus on selecting tasks and framing them in appropriate contexts, guiding students in discussing their ideas, steering them toward important concepts, and creating a productive, comfortable, learning environment.

Students take on new roles with more responsibility in standards-based classrooms. For example, students may initiate their own new activities based on an inquiry task planned by the teacher. In student-generated investigations, they formulate questions and devise ways to answer them, collect data and decide how to represent them, and test the reliability of the knowledge they have generated. As they proceed, students explain and justify their work to themselves and to one another. They respond to challenges posed by the teacher and by classmates. In addition, students set their own goals based on the standards and assess their own work.

This way of teaching may present initial challenges because teachers are asked to give up some control, allowing students to sometimes guide lessons. However, many teachers find this approach to teaching much more rewarding once they become familiar with their new roles. Karen Wilson teaches both mathematics and integrated mathematics and science classes at Shadle Park High School in Spokane, Washington. She does not find it difficult to occasionally give up some control of a lesson. She often finds it the most exciting part of teaching. "When students come up with their own questions and inquiries, it's the best thing that can happen. It shows that the students are engaged and interested. Becoming a problem-poser is a part of learning."

First steps. There is no one best way for teachers to begin integrating the standards into their practice. One possibility is for a teacher to examine the standards and reflect on his or her own teaching. "What are the central messages of the standards? What might classrooms look like if the standards are implemented? What will it take to implement them" (Mumme & Weissglass, 1989)? Reflecting on current practices means that teachers take time to think about what they do and why. "Why do you teach ratio the way you do? Why do you teach [photosynthesis] the way you do? Think about the classes you taught yesterday. How and why were they organized? What beliefs do you hold that influenced your choice of classroom activities? Define your theory of teaching as clearly as possible" (Prevost, 1993).

Karen Wilson has been using the standards for many years. She recommends that teachers begin by familiarizing themselves with the standards and then taking a step back to look at the curriculum and consider what changes to make. She acknowledges that this is a challenging process, because it is likely that choices will have to be made and some topics may be eliminated in order to teach for depth of understanding.

The changes called for by the standards can seem overwhelming. Often, the biggest hurdle is finding a place to begin. Many teachers suggest that it is best to concentrate on one or two recommendations from the standards. Tiffiny Santos is a mathematics facilitator at Beamis Elementary in Spokane, Washington, who helps teachers in implementing the standards. She emphasizes that it is important to start small, making a few changes at a time. She recommends that teachers select areas where they feel strongest and most comfortable. She also finds that it is helpful for teachers to work with partners, either colleagues or facilitators.

Planning. As noted previously, a recommended first step in implementing the standards is a close look at curriculum alignment. Many teachers will find topics that will need to be taken away, added, or moved to different grade levels when they compare the existing curricula and textbooks to state or district standards. Perhaps the most difficult task for teachers is giving up units they have typically taught. Studies have found that in their efforts to address a wide audience, publishers tend to keep adding topics to textbooks without taking anything out (NCES, 1996). Tiffiny Santos acknowledges that the process of narrowing the curriculum is not easy. "It may be very difficult for teachers to give up their favorite lessons and activities." On a more positive note, this can relieve some of the pressure teachers feel to cover such a wide range of material.

Long-range goals for students are important, but teachers will also need to be prepared to adapt these goals into daily or weekly plans that respond to the needs of their students. Above all, plans must be flexible. Because all students are expected to achieve the standards, teachers may need to frequently adjust their plans according to student progress. Teachers need to be able to take more time and create alternative approaches for students who have not understood a concept. At the same time, standards-based teaching requires that other students have opportunities to extend and apply their understanding.

Selecting and designing tasks and units. Teachers are responsible for designing and selecting tasks and units that will provide students with

Designing a standards-based unit of study

1. Identify a unit, topic, or essential question
2. Select the appropriate standards to teach and assess
3. Brainstorm themes, resources, and activities
4. Design and select activities
5. Plan the sequence of activities and instruction, including opportunities for formal and informal assessment
6. Identify criteria for assessment

(Harris & Carr, 1996)

opportunities to gain the knowledge, skills, and abilities outlined in the standards. In order to do this, teachers need to understand what the students are to learn and what they already know (Lappan & Briars, 1995). Teachers should thus design tasks—the standards use the term "tasks" to describe various activities and problems—that provide them with as much information as possible about students' thinking. One way to obtain this information is to incorporate writing into mathematics and science lessons. Writing helps to clarify a student's understanding and reveals misconceptions.

Harris and Carr (1996) suggest that an effective way to select tasks for a unit of study is to divide them into three categories. *Introductory activities* cultivate students' interest and motivate them to participate. *Enabling activities* lead students to build the knowledge, understanding, and skills necessary to attain the standards targeted for the unit and to successfully complete the culminating activity. *Culminating activities* allow students to demonstrate their learning. For planning purposes, it may be beneficial to begin with the culminating activity and work backwards in designing the enabling and introductory activities. This will help focus the unit and guide the selection of lessons and activities. Whenever possible, the activities should lead to products and performances that teachers can use to assess students' progress and learning (Harris & Carr, 1996).

In choosing and creating tasks that address the standards, mathematics teacher Karen Wilson focuses on projects using real-life applications and activities that require problem solving and teamwork. She takes into consideration the value of the task, how to group students, and how the new concept relates to real life and what students have learned before. Wilson finds that applying tasks to real-life situations is very important "because it makes the activity more interesting and because it helps students make sense of what they are learning."

One method of designing standards-based science lessons that actively engage students is to use the learning cycle. In this strategy, instruction progresses through three phases. Students have direct experiences in the exploratory phase before the teacher explicitly introduces the science concepts in the content phase. This helps students connect the abstract concepts to concrete experiences. In the final application phase, students use what they have learned in a new situation (Lawson, Abraham, & Renner, 1989).

Colburn and Clough (1997) suggest a few strategies for using the learning cycle to design activities. Teachers can begin with a lab activity before formally introducing the content of the unit, rather than using labs only to confirm or demonstrate principles. Allowing students to decide how to communicate their lab findings, rather than supplying them with a format, engages them more actively. Tests that include questions requiring students to reflect on their lab experiences can help them to make connections between concepts and lab results. Teachers can also present a question and materials, and allow students to decide what procedures to use (Colburn & Clough, 1997).

Standards-based teaching may require many changes, but this does not mean that teachers need to plan all lessons from scratch. Teachers can take suggested lessons from curriculum guides or textbooks, adapting them to the needs of the students and expanding them into hands-on or problem-solving activities. They can also take their customary lessons and make adaptations as needed.

Kathy Dawes, a middle school science teacher in Moscow, Idaho, recommends taking lab activities from books and modifying them. She finds that most activities do not address the standards, so teachers will need to take a step back and figure out ways to make them truly inquiry-based and problem-solving activities. For example, Dawes created a scenario about a polluted river to provide context for an activity using water samples. Students examined samples and determined what was polluting the river. The students used their data to create a report to a fictional city council, presenting their findings and recommendations on how to solve the problem. Dawes required students to create their own approach using techniques they had learned in previous lessons. In another example, Dawes took an activity on acids and bases, common in science textbooks, and asked students to test the effectiveness of over-the-counter antacids. Students designed their own experiments, choosing tests that would be most appropriate in proving that one product was better than the others. They justified their conclusions using evidence from the investigations.

Although the standards emphasize certain practices, standards-based teaching

Standards-based units:

- Focus students and teachers on attainment of standards
- Address the content and skills presented in the standards
- Make expectations explicit for students and teachers
- Use content and skills to build conceptual understanding
- Provide opportunities for students to work as active learners
- Address important issues and questions generated by the students, the teacher, and the world outside the classroom
- Organize activities and instruction around central problems or themes
- Make assessment an ongoing part of the learning process

(Harris & Carr, 1996)

does not mean always using manipulatives or an inquiry approach. Not all problems must have a real-world context. "There is a time and a place for all kinds of teaching" (Saul, 1997). Using any one of these strategies alone will not magically transform learning. Instead, it is critical that students experience a variety of activities and instructional methods.

Reflective questions

What did you do?

Why did you do it that way?

How did you get your answer?

How can you decide if it is right?

Does it seem to make sense? Why or why not?

Is there another possible answer?

Is there anything else you might try?

Can you explain that in your own words?

What did you learn?

What questions do you still have?

Can you draw a picture of what happened?

Can you show me a model of it?

(Rowan & Bourne, 1993; Stenmark, 1995)

Facilitating discourse. Another important aspect of the teacher's role in a standards-based classroom is facilitating discourse. Interesting context alone does not guarantee that students will automatically get meaning from every classroom activity. Teachers are responsible for posing questions that gently steer students in the right direction without explicitly showing them the way. The standards also ask that teachers use questions that require students to explain and expand on their thinking. Oral and written discourse helps to promote deeper understanding because it calls students' attention to how they know what they know and how it connects to the world beyond the classroom (NRC, 1996).

Overall, the goal is for teachers to do more listening and for students to do more reasoning (NCTM, 1991). In order to develop their knowledge and understanding, students must learn to describe, compare, and discuss their approaches. Classroom discourse should engage all students in speculating and making hypotheses, proposing methods and solutions to problems, and arguing about the validity of their findings and solutions.

Teachers should encourage students to share their thinking and ideas, both right and wrong. The classroom atmosphere must value all contributions, including misunderstandings and mistakes. "Students are more likely to take risks in proposing their conjectures, strategies, and solutions in an environment in which the teacher respects students' ideas, whether conventional or nonstandard, whether valid or invalid" (NCTM, 1991).

Teaching for understanding means going beyond the right answers. When teachers ask students to explain their thinking, they often discover that responses that sound correct actually "mask considerable confusion" (Lerman, 1996). For example, a student may correctly identify one-fourth of a circle, while at the same time thinking that one-fourth is a specific shape rather than a part-whole relationship (Ball,

1992). Teachers should ask students to elaborate on their answers or explain their thinking regardless of whether their answers are right or wrong. Teachers can also facilitate discourse by asking students to write explanations for their solutions.

While the standards emphasize student-led discussions, teachers remain responsible for providing information and leading students. Teachers focus and direct the students' explorations, picking up some ideas and leaving others behind. In order to facilitate discourse, teachers make "decisions about when to let students struggle to make sense of an idea or a problem without direct teacher input, when to ask leading questions, and when to tell students something directly" (NCTM, 1991).

In monitoring discourse, teachers ensure that all students participate. Which students are volunteering comments and which students are not? How are students responding to one another? What are different students able to record or represent on paper about their thinking? What are they able to put into words, in what kinds of contexts (NCTM, 1991)? Students are likely to be accustomed to classes in which the teacher does most of the talking, and they may need encouragement in order to actively participate in classroom discourse.

Creating positive learning environments. Another aspect of standards-based teaching that is closely related to discourse is building a comfortable learning environment. This requires more than classroom management techniques focused on maintaining order. The teacher's role extends to creating an atmosphere "in which students' ideas are respected, where all students participate, and intellectual risk taking is the norm" (McLaughlin & Talbert, 1993).

In a positive learning environment, students have time to think, to try out different approaches, to make mistakes, and to discuss their ideas with each other. The emphasis shifts from quantity and speed to depth of understanding and the quality of students' work.

The teacher is responsible for creating an environment that instills confidence in students and teaches them to value mathematics and science. The classroom must be a safe place for creative and risky thinking, which requires an atmosphere of mutual respect. In addition to mathematics and science learning, students also need to learn the skills necessary for working together. Students must learn how to question each other with respect and to respond without becoming hostile or defensive.

Classroom environment

Are students' thinking, ideas, and questions valued by the teacher and other students?

How much risk is involved in being wrong?

Does the teacher model a positive attitude and good listening skills?

How are disagreements expressed and handled?

How is every student encouraged to participate and learn in class?

(Ball & Schroeder, 1992)

Professional development

The instructional practices called for in the standards emphasize life-long learning and constant refinement. Teachers are asked to think about their teaching and continually evaluate their performance, as well as their students' progress. This practice seems to conflict with the assumption that teachers have learned all they need to know before they begin teaching, a view that has led to a tendency among teachers to keep doubts, questions, and problems to themselves (Schifter, 1996b).

Implementing the standards requires that teachers learn about, develop, and try out new ideas. There are many aspects to creating an environment that fosters the continuous improvement of practice. Teachers take on new roles as researchers, leaders, and peer coaches. They have opportunities to actively participate in groups such as collegial networks, decision-making teams, and support groups. These activities help create an atmosphere of inquiry in which professional learning is an expected and ongoing part of school life.

In a standards-based system, professional learning is a part of all teachers' roles and a part of school culture. However, the public and some policymakers often think that teachers are not working unless they are with their students. This view makes it even more difficult for teachers to obtain the resources and support they need to continue their own learning (McDiarmid, 1995). Standards-based reform in science and mathematics education requires a significant change in teaching practices. "Policies must change so that ongoing, effective, professional development becomes central in teachers' lives" (NRC, 1996).

> BEING A STANDARDS-BASED TEACHER MEANS THAT I AM CONSTANTLY THINKING ABOUT WHAT I DO, COMING UP WITH NEW WAYS TO PRESENT MATERIAL AND CHALLENGE STUDENTS. IT MAKES MY JOB MORE FUN.
>
> —*KATHY DAWES, SCIENCE TEACHER*

Implementing the mathematics and science standards requires a commitment to professional development that goes far beyond one-shot workshops. Teachers should look for activities in which they have opportunities to practice, observe, and analyze effective teaching models (Lieberman, 1995). The most worthwhile workshops and courses are those in which the instructors actually model and use the strategies they are teaching, rather than merely talking about them (Prevost, 1993).

Because teaching is contextual, the ideal professional development activities and support are tailored to the needs of each teacher and are specific to the students in each class. For example, mathematics facilitator Tiffiny Santos helps teachers implement the standards by working with them directly in their classrooms. Santos models lessons, team teaches, observes, and offers ideas and support.

Peer support. Leinwand suggests that implementing the standards should be a "collaborative and supportive process of sharing and experimenting in the con-

text of mutual respect and reflection" (Leinwand, 1992). It is essential that teachers have time for formal and informal discussions with their peers about teaching practices and student learning. They must have opportunities to pose and solve problems, consider new ideas, evaluate alternatives, and set collective goals.

Collegial groups are also a place for teachers to share their feelings about change. They need a chance to express their anxieties and doubts, and to work through their concerns (Mumme & Weissglass, 1989). This requires a great deal of trust and openness. Problems must be viewed objectively, not judgmentally (Osterman & Kottkamp, 1993).

When teachers work together in support groups, they have access to more information about alternative strategies and can provide each other with multiple perspectives. This also expands the pool of resources available to teachers (Osterman & Kottkamp, 1993). Peer support activities can be incorporated into regular department or faculty meetings. Schools and districts can provide time for weekly teacher meetings and team planning. Alternative scheduling practices such as block scheduling also have the potential to provide more time for teachers to work together (Purnell & Hill, 1992; Raywid, 1993).

Assessment. Much of the attention in implementing the standards has focused on assessment. When the standards are seen only as assessment criteria, the purpose of assessment is limited to determining whether or not the standards have been met. However, both the mathematics and science standards emphasize using assessment to guide instruction and identify the needs of students, rather than merely for accountability. In addition to demonstrating student progress, assessment tools can provide teachers with the information they need in planning and conducting their teaching (NRC, 1996).

The standards encourage teachers to use a variety of assessments that are also effective learning experiences. Although pen-and-pencil tests have their place and can be useful, they do not provide a complete picture of student progress and achievement. "Teachers need information gathered in a variety of ways and using a range of sources" (NCTM, 1991). This includes observing groups of students, interviewing students about their understanding of concepts and procedures, and using students' journals to

Questions for self-evaluation

Why did I select these particular learning activities?

In what ways did the activities develop and extend students' understanding?

How did students respond?

How did I encourage students to think and reason?

Did students evoke the level of reasoning that I wanted?

Did I choose good examples?

How did the activities tie in with student needs and interests?

How did the activities build on what students already know?

(NRC, 1996)

✓ Goals were based on long-term student outcomes, not just short-term content mastery.

✓ Content was taught with sufficient time and depth to allow students to develop understanding.

✓ If appropriate, content was connected to related subjects and/or student interests and experiences.

✓ Students were actively engaged in processing information, as well as communicating and testing their understanding.

✓ Skill practice was embedded within meaningful activities such as inquiry or problem solving.

✓ Skills were taught in the context of when and why the skills would be used to accomplish particular purposes.

✓ Classroom discourse focused on thoughtful discussion and creative thinking about key ideas.

✓ Students were required to clarify, elaborate, and justify their answers.

✓ Students were encouraged to interact and debate with each other.

✓ Activities and assignments engaged students in applying the content and using inquiry, creative thinking, problem solving, or other higher-order applications.

✓ Assessment of students' learning focused on understanding and applying content and skills, not just recalling facts and procedures.

(Ornstein, 1995)

monitor their development and attitudes.

Teachers can gain information about student progress from listening and observing during class. This enables them to monitor students' dispositions toward the subjects: their confidence, interest, enjoyment, and perseverance. In addition, teachers can use their observations to modify plans and, more immediately, to adjust questions and tasks to encourage and extend students' thinking (NCTM, 1991).

Assessment is a very complex topic that cannot be dealt with in this small section. The Science and Mathematics Education unit will devote another publication in this series to assessment for the purpose of informing instruction.

Self-evaluation and reflective practice. Teaching in the spirit of the standards means that teachers assess, reflect on, and learn from their own practice. In the classrooms envisioned in the standards, teachers consider assessment data to be a reflection of their practice: What does this data tell me about my performance in the classroom? In addition to providing information about student progress, assessment data indicates whether tasks were worthwhile, meaningful, and effective in leading students to the desired outcomes.

One of the most important sources of information is the students themselves (Heaton, 1996). Mathematics teacher Janice Szymaszek writes, "Through interviews, observations, and conversations I have had with them, the children are teaching me a lot about how they think about numbers and mathematics. I'm learning how to support and challenge their thinking, stimulate their interests, and inspire them to stretch their under-

Questions for reflection

What worked as planned? How do I know?

What would I do differently?

Did students meet the intended objectives? What evidence is there of this?

What insight into the students did I gain?

How can I use this information to improve my instruction?

(Feldt, 1993; Scheibelhut, 1994)

standing to make new discoveries" (Szymaszek, 1996).

Even students' negative reactions, such as boredom, frustration, and confusion, are an opportunity for teachers to learn about their students and improve their practice. When students take a wrong turn or end up with incorrect ideas, the teacher can try to understand why this happened. Science teacher Kathy Dawes asks her students directly for their input. She has them critique activities, explaining what they liked and did not like, as well as suggesting their own ideas for future activities.

The standards require changes that will affect the way many teachers teach, which can be a very difficult process. Teachers will be asked to actively consider and reconsider their beliefs and practices (Posner, 1985). Reflection is a means by which teachers can gain self-awareness about their performance and its impact, which in turn creates opportunities for growth (Osterman & Kottkamp, 1993). The teacher assumes a dual role, both conducting and analyzing his or her own teaching.

Reflection can be an opportunity for a teacher to integrate advice from standards and educational research with his or her own knowledge, past experiences, and goals. Reflective writing can be used to facilitate a teacher thinking deeply about what he or she does in the classroom, and it can be a way to record successes and deal with frustration.

Reflection is not just a solitary practice, but can also take place in a group setting. This requires an atmosphere of trust and support among the teachers in the group. Teachers often gain an even deeper insight into their own beliefs and practices when they must articulate them for their colleagues (Schifter, 1996a).

Conclusion

The changes outlined in the mathematics and science standards are necessary if schools are to promote high expectations for all students. However, schools and classrooms cannot be transformed overnight. Standards-based teaching requires many changes and presents many challenges. Above all, teachers must have time and support to make these new practices their own. The following pages contain a list of resources that teachers can use to help them implement standards-based teaching strategies.

Resources & Bibliography

Resources for further reading

Aldridge, B.G., & Strassenburg, A.A. (Eds.). (1995). *Scope, sequence, and coordination of national science education content standards: An addendum to the content core based on the 1994 draft national science education standards.* Arlington, VA: National Science Teachers Association.

This booklet is intended to align the NSTA *Scope Sequence and Coordination Content Core* curricula with the national science standards. The text is arranged by discipline and by grade level groupings.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy: Project 2061.* New York, NY: Oxford University Press.

Benchmarks supports the Project 2061 initiative of AAAS. The volume specifies grade-level expectations for achieving science literacy as outlined in the 1989 AAAS publication *Science for All Americans.* Rather than a proposed curriculum, *Benchmarks* is a compendium of specific goals that educators and policymakers can use to build new curricula. *Benchmarks* is also available on disk.

House, P.A., & Coxford, A.F. (1995). *Connecting mathematics across the curriculum: 1995 yearbook.* Reston, VA: National Council of Teachers of Mathematics.

Connecting disciplines within mathematics to other subjects of the curriculum, and to the everyday world is an important goal of the NCTM standards. This yearbook, a collection of 26 papers, illustrates these connections and is designed to help K-12 classroom teachers, teacher educators, supervisors, and curriculum developers.

Lindquist, M.M., Dossey, J.A., & Mullis, I.V.S. (1995). *Reaching standards: A progress report on mathematics.* Princeton, NJ: Educational Testing Service.

This report uses the results of the National Assessment of Education Progress (NAEP) over a 20-year period to assess progress on moving students toward the NCTM standards. The report offers both statistical accounting of progress, or lack thereof, and advice from the authors.

National Academy of Sciences. (1996). *Resources for teaching elementary school science.* Washington, DC: Author.

A completely revised edition of the popular resource, *Science for Children: Resources for Teachers*, this book is an annotated guide to hands-on, inquiry-centered, curriculum materials and sources for teaching science from kindergarten through sixth grade. The guide describes approximately 350 curriculum packages and lists recommended materials, kits, suggested equipment, and ordering information.

National Council of Teachers of Mathematics. (1995). *Assessment standards for school mathematics.* Reston, VA: Author.

New assessment strategies and practices need to be developed that will enable teachers and others to assess students' performance in a manner that reflects the vision of the NCTM standards. This book identifies four purposes of assessment: monitoring students' progress, making instruction decisions, evaluating students' achievement, and evaluating programs.

National Council of Teachers of Mathematics. (1991-1995). *Curriculum and evaluation standards for school mathematics: Addenda series.* Reston, VA: Author.

This series is intended to provide teachers with ideas and materials to support the implementation of the *Curriculum and Evaluation Standards for School Mathematics.* The K-6 books are organized by grade level and by mathematical concept or skill area, including *Geometry and Spatial Sense, Making Sense of Data, Number Sense and Operations,* and *Patterns.* The books for grades five to eight cover such topics as geometry, measurement, number sense, data and chance, patterns and functions, and understanding rational numbers and proportions as related to the middle grades. The books for grades nine to 12 include *Algebra in a Technological World, Connecting Mathematics, A Core Curriculum— Making Mathematics Count for Everyone, Data Analysis and Statistics Across the Curriculum,* and *Geometry from Multiple Perspectives.*

National Council of Teachers of Mathematics. (1993). *Implementing the K-8 curriculum and evaluation standards: Readings from the arithmetic teacher.* Reston, VA: Author.

A series of 18 articles reprinted from the 1989-91 issues of the *Arithmetic Teacher,* the articles address each of the K-8 curriculum standards by providing additional interpretations and offering suggestions for implementation.

Sutton, J.T., Marzano, R.J., Kendall, J.S., & Bloom, S.J. (1992). *Mathematical tasks and the NCTM curriculum and evaluation standards.* Aurora, CO: Mid-continent Regional Educational Laboratory.

This book helps teachers create and develop instructional materials and techniques that mirror mathematics tasks recommended by the National Council of Teachers of Mathematics (NCTM).

Virginia Council of Teachers of Mathematics. (1993). *Implementing the mathematics standards* (Virginia Council of Teachers of Mathematics Monographs No. 1 & 2). Salem, VA: Author.

This series was developed for persons interested in the mathematical development of students in grades five through eight.

Organizations

American Association for the Advancement of Science (AAAS)
1200 New York Avenue, N.W.
Washington, DC 20005
(202) 326-6400
http://www.aaas.org/

The American Association for the Advancement of Science is a nonprofit, professional society dedicated to the advancement of scientific and technological excellence across all disciplines, and to the public's understanding of science and technology. AAAS provides a variety of programs, publications, and resources, including *IDEAAAS: Sourcebook for Science, Mathematics, and Technology Education (Third Edition), Science Education News*, and more.

Eisenhower National Clearinghouse for Mathematics and Science Education
The Ohio State University
1929 Kenny Road
Columbus, OH 43210-1079
(614) 292-7784
(800) 621-5785
E-mail: info@enc.org
http://www.enc.org/

This is a nationally recognized information source for K-12 mathematics and science teachers sponsored by the U.S. Department of Education, Office of Educational Research and Improvement. Resources include curriculum materials, a monthly list of outstanding Internet sites, thousands of classroom-ready lessons and activities, and links to other sites.

National Council for Teachers of Mathematics (NCTM)
1906 Association Drive
Reston, Virginia 20191-1593
(703) 620-9840
http://www.nctm.org/

The National Council of Teachers of Mathematics is a nonprofit, professional association dedicated to the improvement of mathematics education for all students in the United States and Canada. All NCTM members receive council publications including regular issues of the *News Bulletin, Student Math Notes*, and one or more of their four journals. The NCTM also publishes books, videotapes, software, and research reports.

National Science Foundation (NSF)
4201 Wilson Boulevard
Arlington, VA 22230
(703) 306-1234
E-mail: info@nsf.gov
http://www.nsf.gov/

The National Science Foundation is an independent, U.S. government agency responsible for promoting science and engineering by funding research and education projects. Information about NSF programs, activities, funding opportunities, current publications, meetings, and conferences is available in a number of publications and online.

National Science Teachers Association (NSTA)
1840 Wilson Boulevard
Arlington, VA 22201-3000
Fax: (703) 243-7177
http://www.nsta.org/

The National Science Teachers Association is the largest organization in the world committed to promoting excellence and innovation in science teaching and learning for all. The association publishes five journals, a newspaper, many books, and a new children's magazine, and conducts national and regional conventions.

Northwest Regional Educational Laboratory (NWREL)
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The Northwest Regional Educational Laboratory provides leadership, expertise, and services to educators and others in the states of Alaska, Idaho, Montana, Oregon, and Washington. The Science and Mathematics Education (SAME) unit provides resources and services in support of effective curriculum, instruction, and assessment, and maintains a lending library of books, videos, and other materials on a variety of topics, including inquiry-based teaching, equity issues, education reform, standards and assessment, and effective instructional practices.

Science and Mathematics Consortium for Northwest Schools (SMCNWS)
Columbia Education Center
171 N.E. 102nd
Portland, OR 97220-4169
(503) 760-2346
Ralph Nelsen, Director
E-mail: ralph@col-ed.org
http://www.col-ed.org/smcnws

The Science and Mathematics Consortium for Northwest Schools is one of 10 regional Eisenhower consortia that disseminate promising educational programs, practices, and materials and provide technical assistance and training in support of state and local initiatives for quality science and mathematics content, curriculum improvement, and teacher enhancement.

Technical Educational Research Center (TERC)
2067 Massachusetts Avenue
Cambridge, MA 02140
(617) 547-0430
http://www.terc.edu

TERC, a nonprofit, education research and development organization, produces the semi-annual publication, *Hands On!,* dedicated to improving mathematics and science learning. The publication reports on the organization's work in creating curriculum, fostering teacher development, conducting research on teaching and learning, and developing technology tools. For subscription contact: Communications@terc.edu

Online resources

Access Excellence: Classrooms of the 21st Century
http://www.gene.com/ae/21st/

This teaching and learning forum explores current issues in curriculum, instruction, and assessment, and connects science teachers with innovators who are developing creative ways to use technology as a tool in classrooms.

Busy Teachers' WebSite
http://www.ceismc.gatech.edu/BusyT/TOC.html

This site is designed to provide K-12 teachers with direct source materials, lesson plans, and classroom activities with a minimum of site-to-site linking. Mathematics, science, and other topics are covered. Links to Internet discussion groups for educators (and students) are provided.

Center of Excellence for Science & Mathematics Education (CESME)
http://cesme.utm.edu/

Located at the University of Tennessee at Martin, the mission of CESME is to encourage and support the improvement of science and mathematics education at all levels. This Web site is designed to serve as a starting point for teachers who are looking for resources to improve their science or mathematics teaching. It provides a good collection of links, lesson plans, projects, and other resources relevant to standards-based teaching.

Curriculum and Evaluation Standards for School Mathematics
http://www.enc.org/reform/

This NCTM publication is maintained online by the Eisenhower National Clearinghouse for Mathematics and Science Education. Select "Standards and Frameworks" to view this document, other standards publications, and links to other standards-related sites.

Developing Educational Standards
http://putwest.boces.org/standards.html#Section3

Putnam Valley Schools in New York established this page as a repository for as much information about educational standards and curriculum frameworks from all sources (national, state, local, and other) as can be found on the Internet. It provides annotated lists and links to all known standards and frameworks documents. Information at this site is updated frequently.

Exemplars: A Teacher's Solution
http://www.exemplars.com/index.html

Exemplars was founded to assist teachers, schools, and districts to implement authentic assessment and problem solving in classrooms that is aligned with national and state standards for mathematics and science. The site provides teacher-developed and classroom-tested assessment problems in mathematics for grade levels K-12 and in science for grade levels K-8. Each problem includes rubrics based on national standards and sample anchor papers. Exemplars also maintains a monthly *News and Notes* column.

Explorer
http://explorer.scrtec.org/explorer/

Explorer offers information about mathematics and science software programs, CDs, and print material. From Explorer's home page, you can conduct searches by category or content outline in mathematics or science directories. The search generates a list of relevant resources, including brief descriptions and the correlation to national standards. In many cases, the resource is free or low-cost software that you can download directly.

Kathy Schrock's Guide for Educators
http://www.capecod.net/schrockguide/index.htm

This is a guide to sites on the Internet that are useful for enhancing curriculum and teacher professional growth. The site is updated daily.

National Science Education Standards
http://www.nap.edu/readingroom/books/intronses/

The National Academy Press of the National Academy of Sciences has placed the *National Science Education Standards* online. Individual pages contain narratives explaining each standard and suggested teaching strategies. Particularly useful are the numerous links to other pages in the standards document, making it easy to follow a side path and then come back to the page you started on.

Northwest Regional Educational Laboratory
Curriculum & Instruction
http://www.nwrel.org/psc/ci/

The goal of NWREL's Curriculum and Instruction services is improved teaching and learning schoolwide; the primary focus is the classroom. Select "Standards."

Pathways to School Improvement
http://www.ncrel.org/sdrs/pathwayg.htm

A number of documents located at this site address issues related to the national science and mathematics standards, including *Implementing Curriculum, Instruction and Assessment Standards in Mathematics/Science.* Summaries and links to original text are provided for relevant legislation and other items, such as Goals 2000: Educate America Act, National Education Goals and Objectives, and the Standards and Benchmarks. See:

Goals and Standards
http://www.ncrel.org/sdrs/areas/gs0cont.htm

Critical Issue: Providing Hands-On, Minds-On, and Authentic Learning Experiences in Mathematics
http://www.ncrel.org/sdrs/areas/issues/content/cntareas/math/ma300.htm

Project 2061: Science Literacy for a Changing Future
http://project2061.aaas.org/

This site, maintained by the AAAS, has the *Benchmarks for Science Literacy* online, and extensive information regarding Project 2061.

State Standards:

Alaska
http://www.educ.state.ak.us/ContentStandards/home.html

Idaho
The Eisenhower National Clearinghouse has placed the *1994 Idaho K-12 Mathematics and Science Content Guides and Frameworks* online.
Mathematics
http://www.enc.org/reform/fworks/ENC3208/nf_3208.htm
Science
http://www.enc.org/reform/fworks/ENC2972/nf_2972.htm

Montana
http://www.enc.org/reform/fworks/ENC1665/nf_1665.htm
The Eisenhower National Clearinghouse has placed the *Montana Toolkit for Mathematics Curriculum Development* (1994 draft) online.

Oregon
http://www.ode.state.or.us//

Washington
http://csl.wednet.edu/
This Commission on Student Learning site links to the *Essential Academic Learning Requirements*, Washington's state standards.

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